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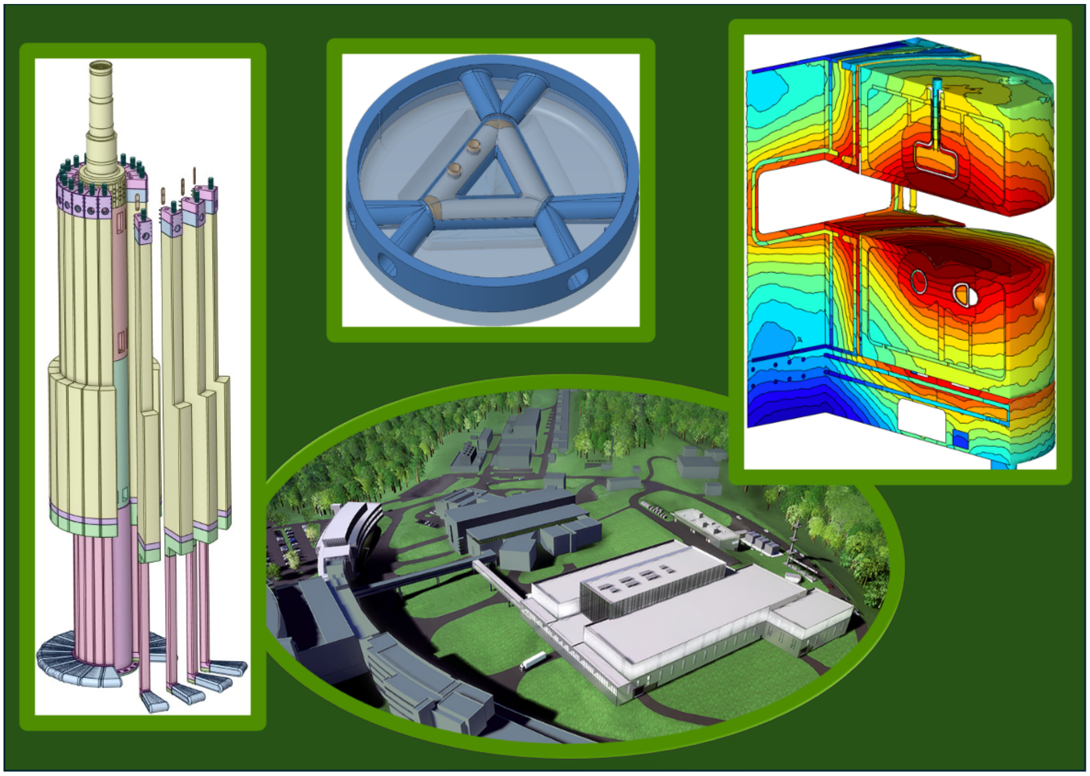
Energy Deposition and Radiation Damage in ORNL's Second Target Station Final Design of the Target and Target Shaft



Lukas Zavorka

February 2026

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Second Target Station Project

ENERGY DEPOSITION AND RADIATION DAMAGE IN ORNL'S SECOND TARGET STATION FINAL DESIGN OF THE TARGET AND TARGET SHAFT

Lukas Zavorka

February 2026

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ABBREVIATIONS

CAD	Computer Aided Design
cc	Cubic centimeter or cm^3
CPU	Central Processing Unit
CSG	Constructive Solid Geometry
CV	Core Vessel
dpa	Displacement per atom
FTS	First Target Station at SNS
FW-CADIS	Forward-Weighted Consistent Adjoint Driven Importance Sampling
MRA	Moderator Reflector Assembly
ORNL	Oak Ridge National Laboratory
PBW	Proton Beam Window
SNS	Spallation Neutron Source
STS	Second Target Station at SNS
UM	Unstructured Mesh
VR	Variance Reduction
ZAID	Proton and neutron isotopic identification number

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EXECUTIVE SUMMARY

This report discusses calculations of energy deposition and radiation damage in ORNL's Second Target Station (STS) target and target shaft based on the final-design geometry from July 2025. Calculations were performed with the radiation transport code MCNP6.2 [1] and they used Unstructured Mesh (UM) geometry models of the components. The UM models were converted from the original solid Computer Aided Design (CAD) models with Attila4MC [2]. The UM models maintain high level of fidelity and provide neutronics results with high spatial resolution, which is especially important for the subsequent structural stress and thermal analyses.

Energy deposition calculations were performed with several versions of the incident proton beam to cover all expected operational conditions (nominal and off-normal) under which the beam can be delivered to the STS. These conditions include nominal, overfocussed, diffused, and maximally shifted beam conditions.

The report shows that the final-design geometry satisfies requirement 2301 – Segment Displacements per Atom (dpa) limit, which requires that "The materials in the segment shall not exceed DPA-NRT limits specified in the Second Target Station materials handbook". The report also shows that the lifetime of the target shaft due to radiation damage is 125 years, well above the expected lifetime of the STS facility.

1. SCOPE

This report documents a series of MCNP radiation transport (neutronics) calculations performed to deliver high-spatial resolution data of energy deposition and radiation damage in the final design geometry of the STS target and target shaft. The energy deposition data serve as input for the subsequent structural stress, thermal, and other engineering analyses. Data on radiation damage determine the lifetime of the components due to radiation-induced effects, quantified as displacements per atom (dpa).

2. ACCEPTANCE CRITERIA

Results on radiation damage presented in this study show that the target final design geometry satisfies Requirement 2301 – Segment dpa limit.

3. ASSUMPTIONS AND LIMITATIONS

This analysis was performed using the solid CAD model "s03020000-m8u-8800-a10000_asm-v167-analysis.stp" for target segment and target shaft from July 11, 2025, known at that point to represent the STS final-design geometry. Results do not capture any subsequent design developments or modifications.

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4. METHODOLOGY AND MODELS

4.1 MODELS FOR THE ANALYSIS

This analysis uses a solid CAD model "s03020000-m8u-8800-a10000_asm-v167-analysis.stp" for 20 target segments and target shaft from July 11, 2025. These components are surrounded by the moderator-reflector assembly (MRA), core vessel (CV), core vessel shielding, and proton beam window (PBW). More distant STS components, such as the target crown in the target drive room, accelerator components, neutron beamline components and distant shielding components are not included in the MCNP model for this analysis, because they have negligible impact on the results and their incorporation would significantly slow down MCNP calculations. The solid CAD model of the target and target shaft up to the elevation of 469.3 cm above the proton beam axis is shown in Figure 1 and more detailed elevation plot and horizontal view of the components are shown in Figure 2.

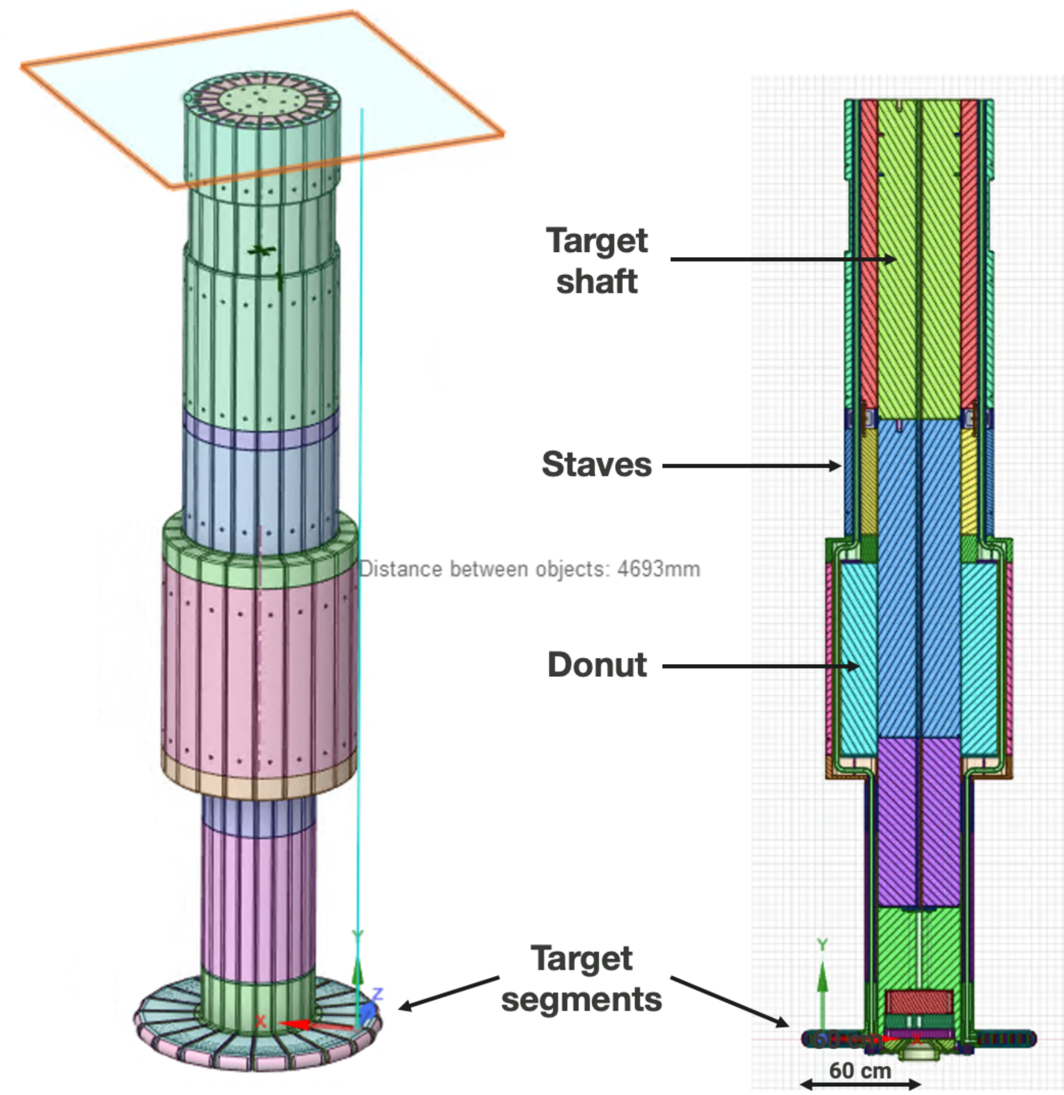

Figure 1. 3D view (left) and elevation plot (right) of the target segments and target shaft.

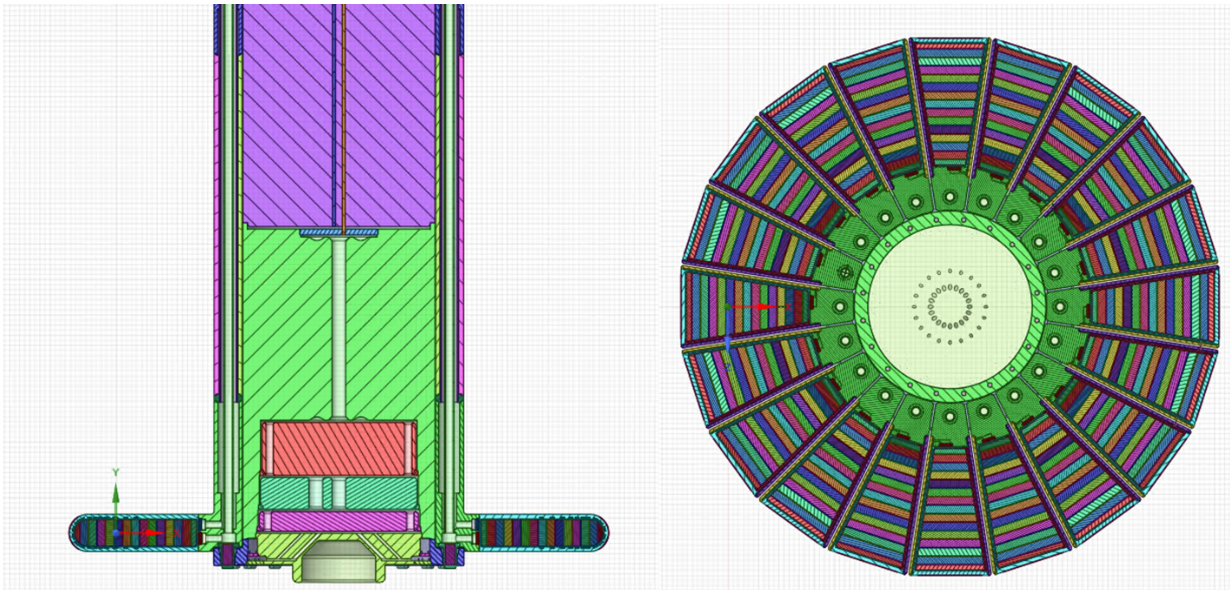

Figure 2. More detailed elevation plot (left) and horizontal cross section (right) of the lower portion of the target segments and target shaft.

4.2 CAD TO MCNP CONVERSION

The solid CAD model was converted into the unstructured mesh (UM) model for neutronics calculations with Attila4MC's tetrahedral mesh generator in the non-manifold non-imprint mode, which results in contiguous mesh with no overlaps of the neighboring objects. Such a mode is extremely important to use for detailed energy deposition calculations compared with the default part-by-part mesher that can generate discontiguous mesh with possible mesh overlaps, resulting in potentially incorrect results in mesh elements on adjacent objects boundaries.

Mesh generation parameters are summarized in Table 1 and Table 2 for the target segment and target shaft, respectively. The selection of the meshing parameters results in good compromise between the high-fidelity of the UM model, as required by the subsequent engineering analyses, and efficiency or speed of the MCNP calculations and limits of the hardware. In general, the finer the UM model and the higher the number of mesh elements, the more MCNP computing time and CPU memory is necessary to reach results with good statistical uncertainty. A reasonable computing time that is available – given by the existing STS neutronics hardware and the need to complete a range of other analyses within the STS project – is maximally about a week to 10 days occupying one half of the nodes available on Kryo cluster, which provides 448 computer processors (CPUs) with almost full memory usage.

The setting of meshing parameters results in a target segment that is composed of 350,000 mesh elements in the elevation profile between the two STS moderators (within -5 cm < Y< +5 cm). The total number of mesh elements in the entire MCNP model for this analysis is approximately 10,000,000 which is at the limit of the available computer memory.

Figures 3-6 provide comparison between solid CAD models and UM models of the target segment and target shaft. In Figures 4-6, several components are intentionally hidden to display the objects below the surface of the most outside components. Figure 4 shows water cooling channels and Figure 5 shows tungsten plates. Figure 7 shows the integration of the UM models of the target and target shaft in the final MCNP model with the moderators and shielding, as displayed by the MCNP plotter.

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Table 1. Most important Attila4MC meshing parameters for the target segment

Meshing parameter type	Meshing parameter value
General max allowable edge length	0.0075 m
Max allowable edge length for components upstream the 6th tungsten plate	0.005 m
Max allowable edge length for components downstream the 6th tungsten plate	0.0075 m
Size transition factor	0.4
Maximum d/h ratio	0.02
Minimum edge length	0.025
Anisotropic refinement	yes

Table 2. Most important Attila4MC meshing parameters for the target shaft

Meshing parameter type	Meshing parameter value
General max allowable edge length	0.15 m
Max allowable edge length for steel components below the elevation of 1m	0.03 m
Max allowable edge length for water below the elevation of 1 m	0.025 m
Max allowable edge length for water below the elevation of 0.5 m	0.01 m
Size transition factor	0.4
Maximum d/h ratio	0.02
Minimum edge length	0.025
Anisotropic refinement	yes

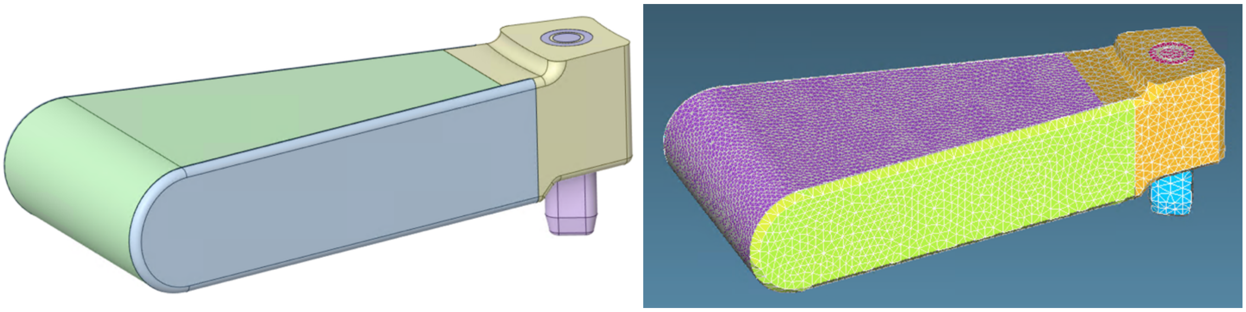

Figure 3. CAD model (left) and UM model (right) of the target segment.

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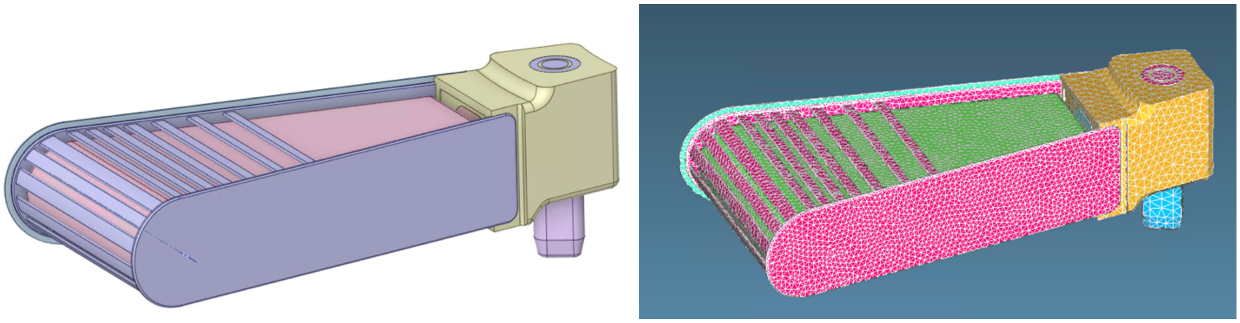

Figure 4. CAD model (left) and UM model (right) of the target segment without Inconel-718.

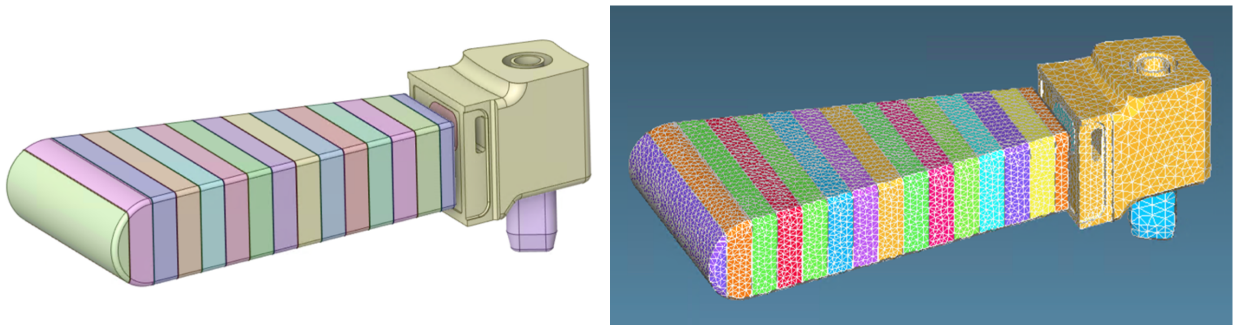

Figure 5. CAD model (left) and UM model (right) of the target segment without Inconel-718, water, and tantalum.

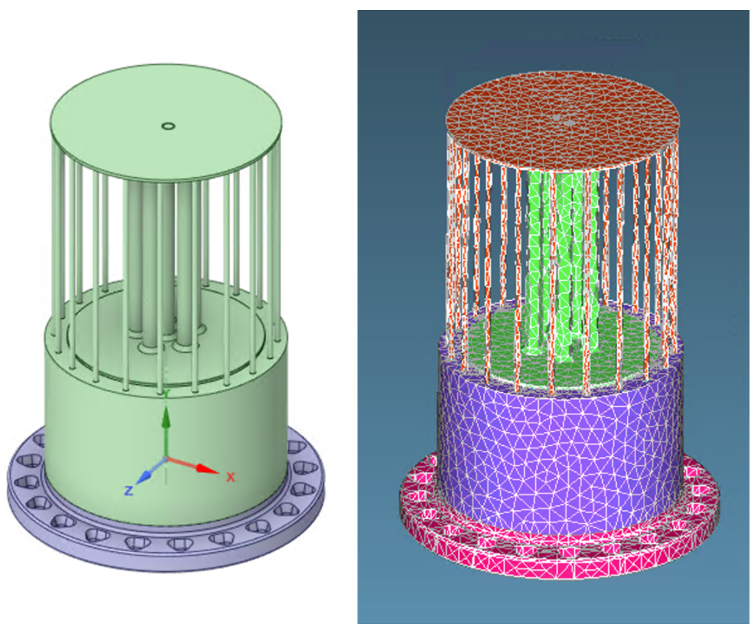

Figure 6. CAD model (left) and UM model (right) of the lower portion of the target shaft, with partially hidden steel portion to show water channels.

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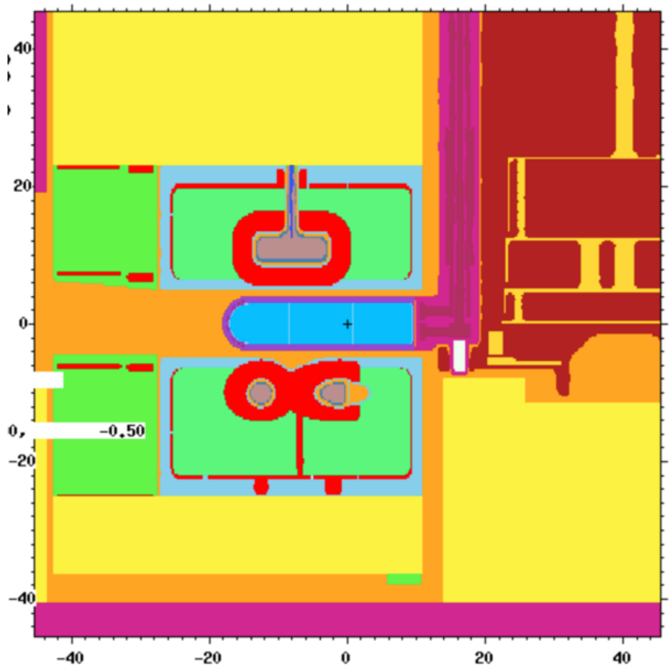

Figure 7. Elevation plot of the central portion of the geometry, including the target segment, target shaft, MRA, and CV shielding, as displayed by the MCNP plotter.

4.3 MATERIALS AND PHYSICS MODELS

Material composition of the most important materials (tungsten, tantalum, stainless steel 316, Inconel-718, copper chromium zirconium alloy, and water) used in this MCNP analysis are summarized in Tables 3-8. ZAID is the proton and neutron identification number. By default, the ENDF/B-VII.1 nuclear data library is used for neutron interactions, with the ENDF/B-VII.0 library used for tungsten and tantalum, because the library reduces the number of segmentation faults during the MCNP calculations with UM and thus the number of required continuous restarts. The frequency of the segmentation faults is also significantly reduced by the high-quality UM, which contains no mesh overlaps.

Nuclear data libraries are used for neutron interactions below 20 MeV. Above this energy and for all high-energy charged particle interactions, the MCNP calculations in this analysis use the CEM03.03 physics model with the default setting of the model physics cards.

Table 3. Tungsten. Density 19.3 g/cm^3. STS neutronics mat #12, ENDF/B-VII.0 library

ZAID	Atomic fraction	ZAID	Atomic fraction	ZAID	Atomic fraction
74182	0.2653	74183	0.1433	74184	0.3068
74186	0.2846				

Table 4. Tantalum. Density 16.6 g/cm^3. STS neutronics mat #14, ENDF/B-VII.0 library

ZAID	Atomic fraction
73181	1.0

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Table 5. Stainless steel 316 composition. Density 8.0 g/cm^3. STS neutronics mat #252, ENDF/B-VII.1 library

ZAID	Weight fraction	ZAID	Weight fraction	ZAID	Weight fraction
6000	4.099949e-4	14028	0.004657923	14029	0.000244800
14030	0.000167194	15031	0.000229818	16032	0.000141906
16033	1.1551E-06	16034	6.6798E-06	16036	3.3601E-08
24050	0.007102731	24052	0.142276576	24053	0.016441745
24054	0.004179124	25055	0.010140357	26054	0.037801314
26056	0.614798022	26057	0.014459771	26058	0.001943253
28058	0.080641263	28060	0.032127494	28061	0.001420162
28062	0.004596109	28064	0.001215537	42092	0.003553938
42094	0.002263389	42095	0.003936990	42096	0.004168349
42097	0.002411473	42098	0.006155910	42100	0.002506990

Table 6. Inconel-718. Density 8.19 g/cm^3. STS neutronics mat #102, ENDF/B-VII.1 library

ZAID	Weight fraction	ZAID	Weight fraction	ZAID	Weight fraction
5010	9.1729E-06	5011	4.0852E-05	6000	7.299396E-04
13027	0.005000044	14028	0.002921583	14029	0.000153546
14030	0.000104869	15031	0.000140088	16032	0.000132664
16033	1.0799E-06	16034	6.2448E-06	16036	3.1413E-08
22046	0.000712789	22047	0.000656782	22048	0.006645872
22049	0.000497883	22050	0.000486426	24050	0.007938359
24052	0.159015243	24053	0.018376096	24054	0.004670793
25055	0.003179703	26054	0.009605737	26056	0.156227057
26057	0.003674390	26058	0.000493802	27059	0.009100251
28058	0.352804911	28060	0.140557543	28061	0.006213196
28062	0.020107941	28064	0.005317963	29063	0.001869891
29065	0.000859899	41093	0.051249547	42092	0.004336007
42094	0.002761463	42095	0.004803351	42096	0.005085623
42097	0.002942134	42098	0.007510560	42100	0.003058670

Table 7. Copper Chromium Zirconium alloy. Density 8.89 g/cm^3. STS mat #332, ENDF/B-VII.1 library

ZAID	Weight fraction	ZAID	Weight fraction	ZAID	Weight fraction
14028	9.186649e-04	14029	4.833629e-05	14030	3.299884e-05
24050	5.008424e-04	24052	1.004392e-02	24053	1.160830e-03
24054	2.944037e-04	26054	4.516447e-05	26056	7.352122e-04
26057	1.728295e-05	26058	2.340355e-06	29063	6.732874e-01
29065	3.099126e-01	40090	1.521184e-03	40091	3.354266e-04
40092	5.183431e-04	40094	5.367331e-04	40096	8.831367e-05

Table 8. Ambient light water. Density 1.0 g/cm^3. STS neutronics mat #9, ENDF/B-VII.1 library

ZAID	Atomic fraction	ZAID	Atomic fraction
1001	2	8016	1

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4.4 ENERGY DEPOSITION TALLY

This analysis uses a set of embedded elemental edits control cards EMBEE type 6 to individually tally the energy deposition contributions from neutrons, photons (and electrons), protons, deuterons, tritons, alpha particles, and charged pions. These contributions are summed together for every single mesh element and exported in the .csv format for individual target segments and target shaft and for individual materials. The .csv files serve as input for the subsequent engineering analyses.

Figure 8 illustrates calculated energy deposition in a portion of the front target segment impacted by the proton beam. It shows the UM model of the segment, horizontal cross section through the target front, and the tallied energy deposition in that portion of the target. Every single mesh element represents a data point in the output .csv file.

In the early stages of the STS project and elsewhere [3,4], a significant amount of time was spent on validating the energy deposition on UM in the spallation environment. Comparisons between EMBEE type 6 cards and traditional MCNP energy deposition tallies type +F6 and type 3 TMESH mesh tallies resulted in consistent agreement on both UM and traditional MCNP constructive solid geometries (CSG).

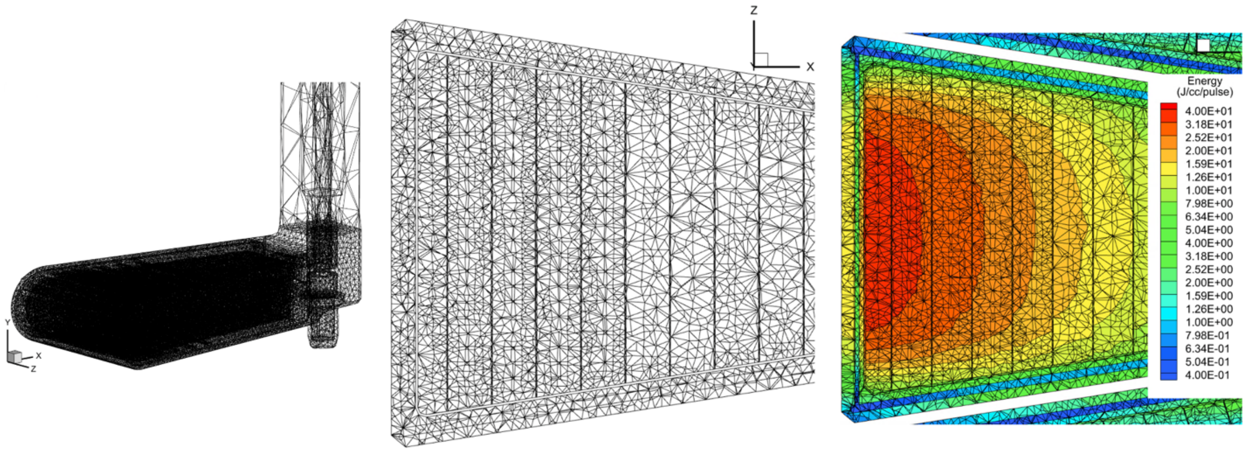

Figure 8. Example of energy deposition on UM in the target front.

4.5 RADIATION DAMAGE CROSS SECTIONS AND TALLY

This analysis uses a set of radiation damage cross sections developed at SNS' First Target Station (FTS) by Wei Lu [5] that extends up to 3.2 GeV for both neutrons and protons. Displacement per atom (dpa) is calculated individually for all materials: tungsten, tantalum, stainless steel 316, Inconel-718, and copper (as a substitute for copper chromium zirconium alloy with 98.5% content of copper). Dpa cross sections are shown for neutrons and protons in Figure 9 and Figure 10, respectively.

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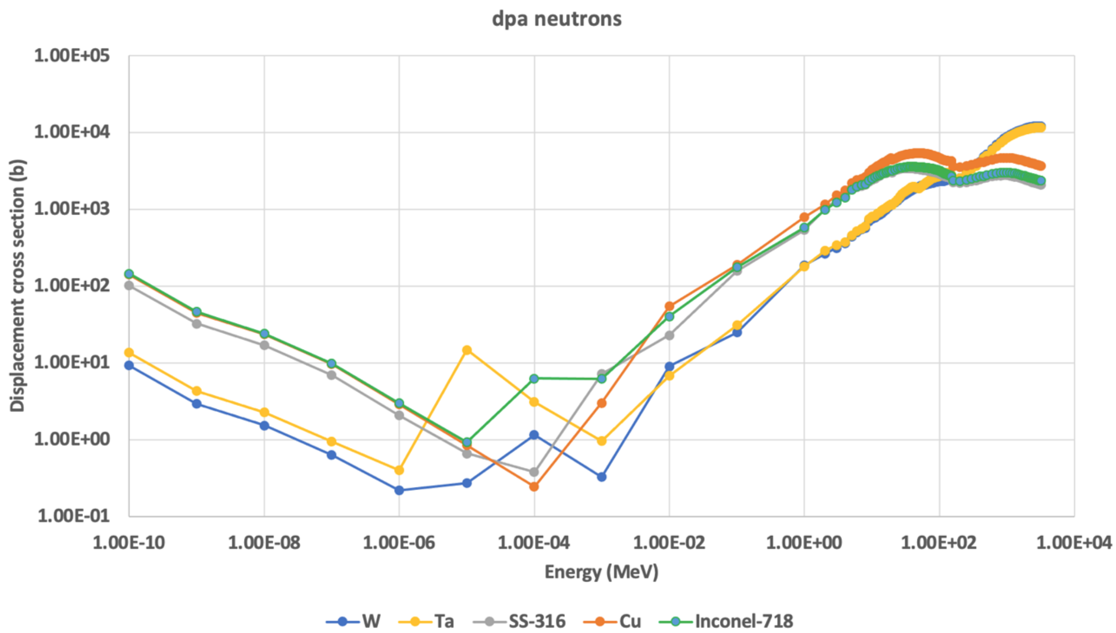

Figure 9. Applied dpa cross sections for neutrons [5].

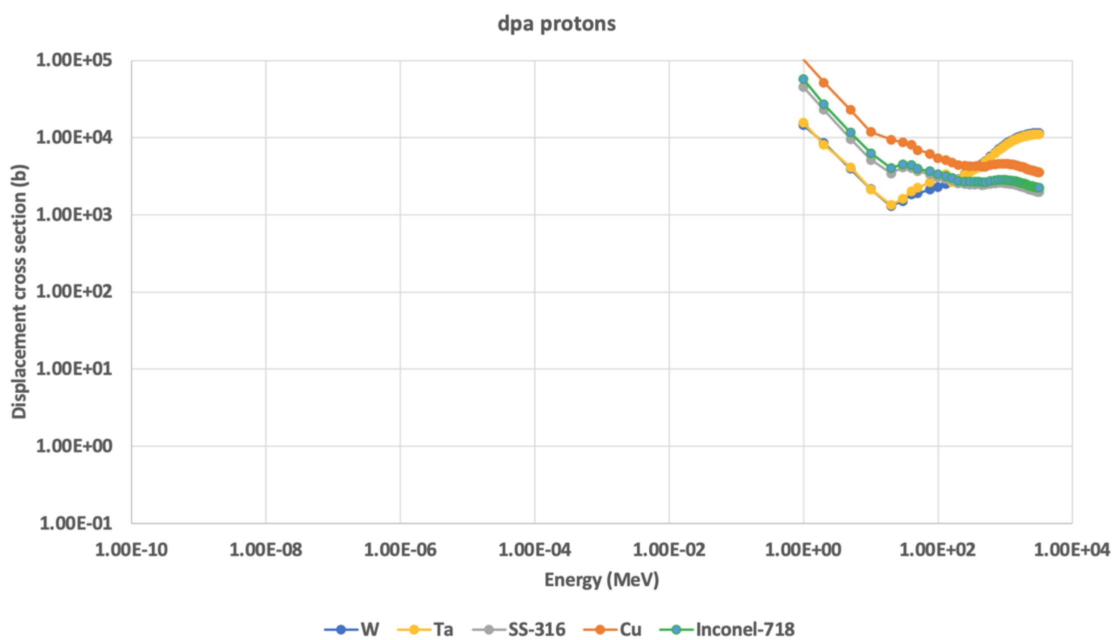

Figure 10. Applied dpa cross sections for protons [5].

Dpa cross sections are inserted into MCNP calculations on embedded elemental edit dose energy-bin multipliers cards EMBDF and energy-bin boundaries cards EMBDE as a portion of the elemental edits control cards EMBEE type 4. Neutron and proton displacement cross sections are located on separate cards and the results from both cards are summed together for each material. Results are reported as dpa per one proton pulse (dpa/pulse), which is 2.24E14 protons.

To report maximum radiation damage as dpa per one year of operation (dpa/year), which is 5,000 hours at 15 pulses/second, the results are further integrated at the same spatial locations within the individual target segments, assuming that there are 20 segments in the rotating target. Results are multiplied by a factor of 10 to get dpa per 10 years to compare them with the lifetime limits of the components.

4.6 VARIANCE REDUCTION AND UNCERTAINTY

Typically, results with good statistical uncertainty can be obtained in a reasonable computing time without the use of MCNP variance reduction (VR) methods only within approximately 1 m from the target (the front target segment impacted by the beam). This means that both energy deposition and radiation damage can be calculated without VR in all target segments and lower portion of target shaft up to the elevation of about 80 cm above the proton beam axis. To calculate energy deposition and radiation damage at higher elevations of the rotating target shaft, variance reduction tools must be used.

This analysis uses a VR method called weight windows calculated with Attila4MC's Cottonwood deterministic solver. The solver uses Forward-Weighted Consistent Adjoint Driven Importance Sampling (FW-CADIS) methodology [6] to calculate coupled neutron-photon weight windows throughout the entire geometry with a motivating tally located in the upper portion of the shaft. HILO2k cross section library [7] that extends up to 2 GeV was used in the deterministic calculation. Weight windows were imported in MCNP on an external WWINP file.

Final results of energy deposition and radiation damage were combined from two MCNP runs, one for elevations below Y=80 cm without the use of weight windows and the other for elevations above Y=80 cm with the application of weight windows, ensuring smooth transition between the data sets.

In general, the relative statistical uncertainties of the MCNP calculations in the crucially important and well converged regions are below 3%. This does not include the uncertainty in nuclear data and high-energy nuclear physics models, estimated cumulatively as less than 10%.

5. RESULTS

5.1 ENERGY DEPOSITION UNDER NOMINAL BEAM CONDITIONS

Energy deposition was calculated in the target and target shaft up to the elevation of 469.3 cm above the proton beam axis using the nominal proton beam profile, which is 60 cm^2. In this analysis, protons start at a distance of 3 m from the target, upstream of the proton beam window (PBW) to realistically simulate the scattering of protons as they pass through the PBW.

Figure 11 illustrates the energy deposition in the target segments and lower portion of the shaft. Figure 12 shows energy deposition in the entire length of the shaft up to the target drive room. Note that the increased relative errors in the upper portion of the shaft do not cause significant issue given the absolute values of the deposited energy compared to the peak energy deposition in the target segments and lower portion of the shaft, which is many orders of magnitude higher.

The peak energy deposition in the front target segment is in tungsten and is 38.1 J/cm^3/pulse. Total heating in tungsten in all target segments, assuming 15 proton pulses per second, is 293 kW. Total heating in all materials in all target segments of the target wheel (excluding the shaft) is 378 kW.

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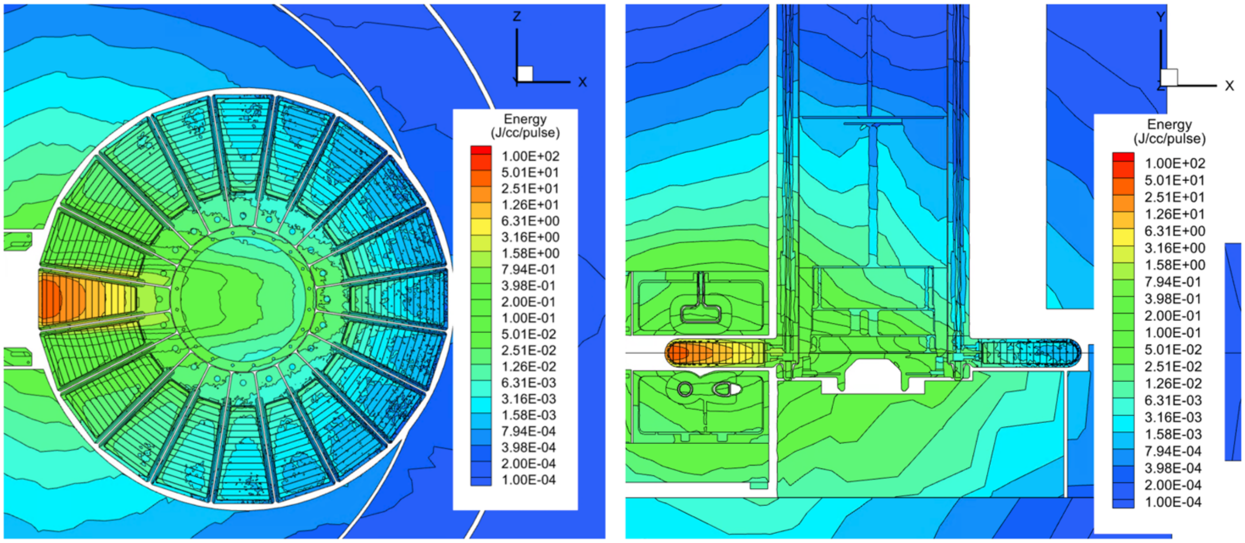

Figure 11. Horizontal view (left) and elevation plot (right) of the energy deposition in target segments and lower portion of the shaft.

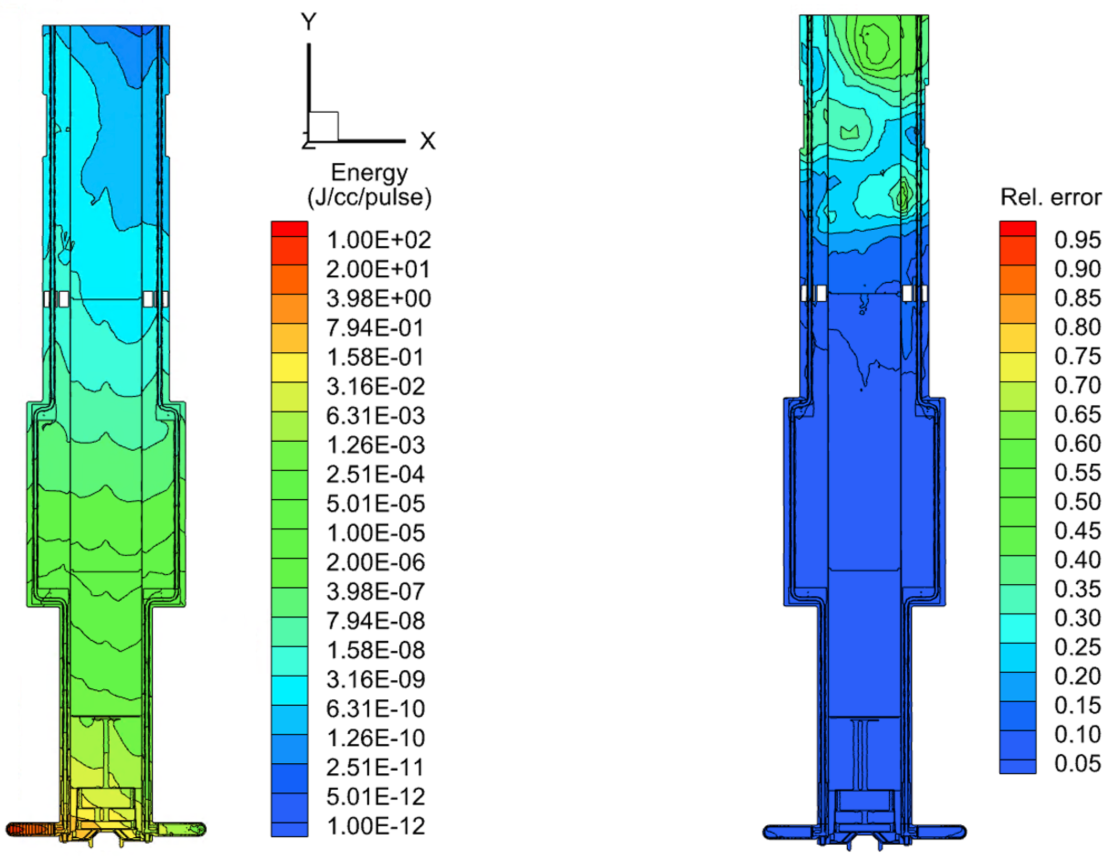

Figure 12. Elevation plot of the energy deposition in the full target shaft (left) and relative statistical uncertainty from neutrons (right).

5.2 ENERGY DEPOSITION UNDER OFF-NORMAL BEAM CONDITIONS

Off-normal proton beam conditions were specified as: i) offset 60-cm^2 nominal beam shifted by 12 mm horizontally and 8.5 mm vertically, ii) overfocused 57-cm^2 beam, and iii) diffused 94.5 cm^2 beam. Additional details about the proton beam conditions are listed in Appendix C. Results from calculations under these beam conditions are summarized in Table 9 and they are also compared with the nominal beam conditions in Figure 13. As expected, maximum peak energy deposition and maximum heating was calculated for the case with overfocused beam.

Table 9. Peak energy deposition and heating results under various beam conditions.

	Nominal	Offset	Overfocused	Diffused
Peak energy deposition (J/cm^3/pulse)	38.1	38.2	40.0	25.8
Total heating in tungsten (kW)	293	274	296	263
Total heating in all target materials (kW)	378	370	379	371

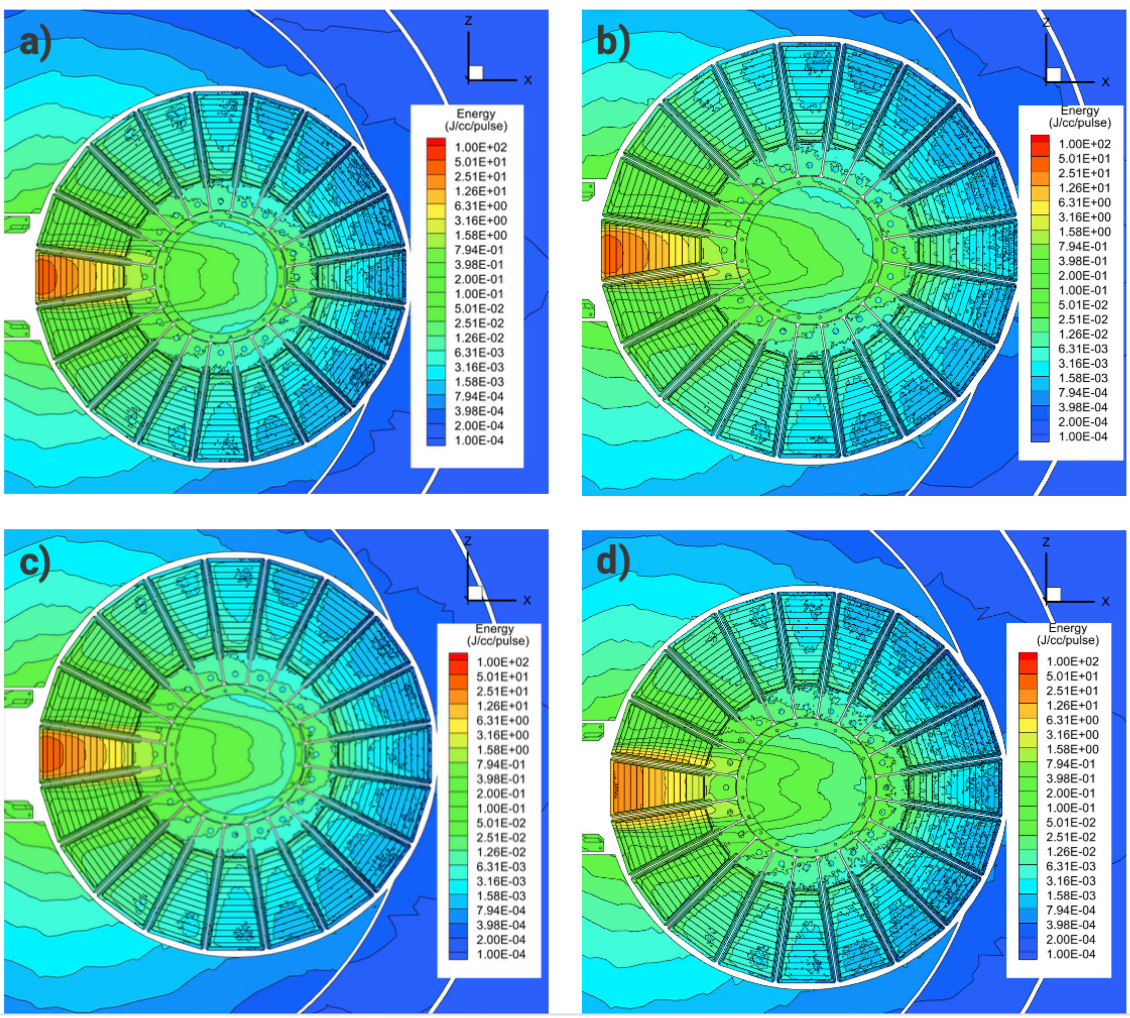

Figure 13. Horizontal view of the energy deposition in the target wheel under a) nominal beam conditions, b) offset beam, c) overfocused beam, and d) diffused beam.

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5.3 ENERGY DEPOSITION TEMPERATURE SENSITIVITY STUDY

As the proton beam impacts the front target segment and deposits its energy, the temperature in that segment increases up to 225 ºC [8]. By default, all materials in this study (except liquid hydrogen and moderator vessels) use neutron cross sections at 20 ºC. To study the effect of increased temperature on energy deposition in the target, two modifications of the MCNP input file were performed.

First, the temperature in tungsten plates of the front target segment was increased to the realistic temperature profile from [8] using the TMP card. This card only impacts the thermal treatment of low-energy neutron transport. As a result, no noticeable difference was observed between the energy deposition data with and without using this card.

Second, a set of ENDF/B-VII library neutron cross sections was used for tungsten and tantalum within the target segments at the next available temperature, which is 327 ºC (or 600 K). No standard set of cross sections is available closer to the maximum tungsten temperature of 225 ºC between 20 ºC and 327 ºC. An MCNP calculation with this cross-section data set resulted in 0.05% increased heating in the front target segment, which is well below the statistical uncertainty of the data. It is expected that at 225 ºC, this difference is less than 0.05%. Since this difference is very small, no further effort (such as the generation of neutron cross sections with NJOY at 225 ºC) was initiated, but can be done later.

It is worth noting that the latter modification only impacts the energy deposition from neutrons below 20 MeV, and does not impact energy deposition from high-energy particles, controlled by the CEM03.03 physics model. To study the impact of increased temperatures on MCNP high-energy modeling is beyond the scope of this analysis.

5.4 RADIATION DAMAGE

Radiation damage expressed as a number of displacements per atom was calculated in the target and target shaft up to the elevation of 469.3 cm above the proton beam axis using the nominal proton beam. Results per one proton pulse are shown in Figure 14 for tungsten and in Figures 15-16 for other materials of the target. Figure 17 is the elevation plot of radiation damage in steel portion of the target segment and in the lower portion of the shaft. Figure 18 is the elevation plot of the radiation damage per one pulse in the full target shaft.

Dpa values were integrated at the same coordinates within the 20 individual target segments. Assuming 15 proton pulses per second, the maximum dpa values within the segments were determined for all materials and they are presented in Table 10. This table also contains material lifetime limits given by Requirement 2301 – Segment dpa limit, which refers to the STS Materials Handbook [9] and states that the damage shall not exceed 9 dpa in tantalum, 10 dpa in Inconel 718, and 15 dpa in stainless steel. Tungsten and copper are not considered as structural materials and do not have lifetime limits. Table 10 shows that the maximum calculated damage is below the lifetime limits after 10 years of operation.

Table 10. Maximum radiation damage per 10 years of operation and corresponding lifetime limits according to requirement 2301 in individual materials of the target segment.

Material	This analysis (dpa/10 years)	Lifetime limit (dpa)
Tungsten	8	Not a structural component
Tantalum	8	9
Stainless steel 316	2	15
Inconel-718	6	10
Copper	2	Not a structural component

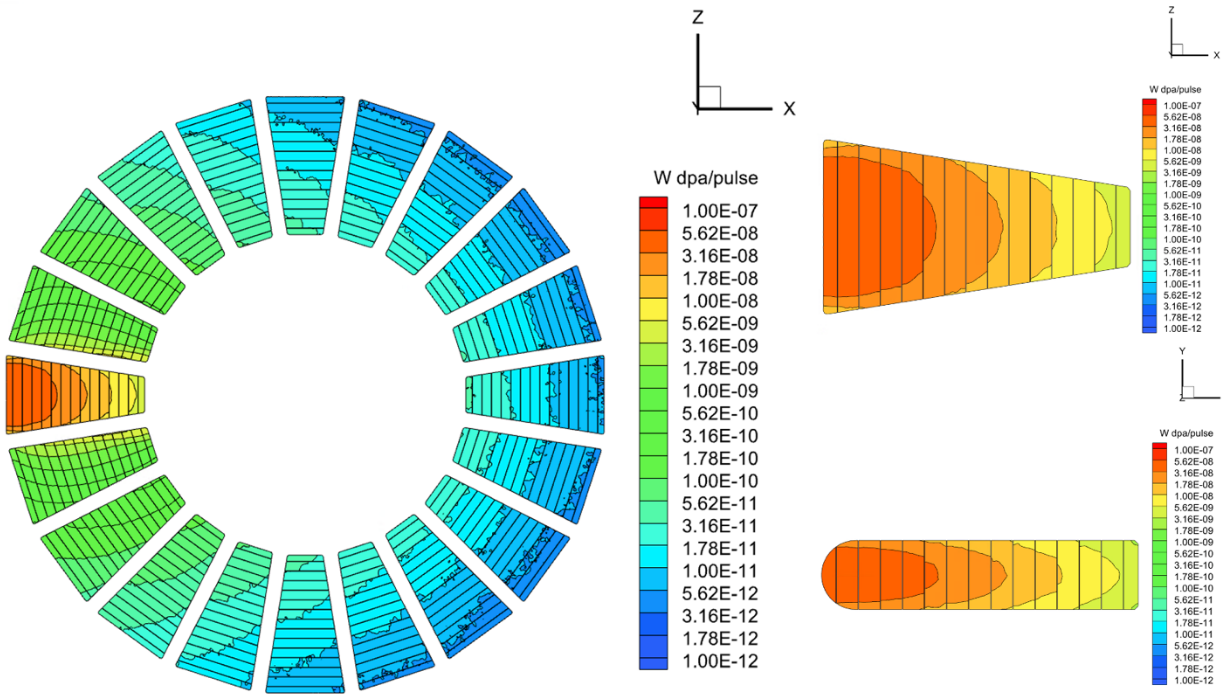

Figure 14. Radiation damage per one pulse in tungsten. Horizontal view of the target wheel (left), with a detailed view of the front target segment (top right), and the elevation plot of the detail (bottom right).

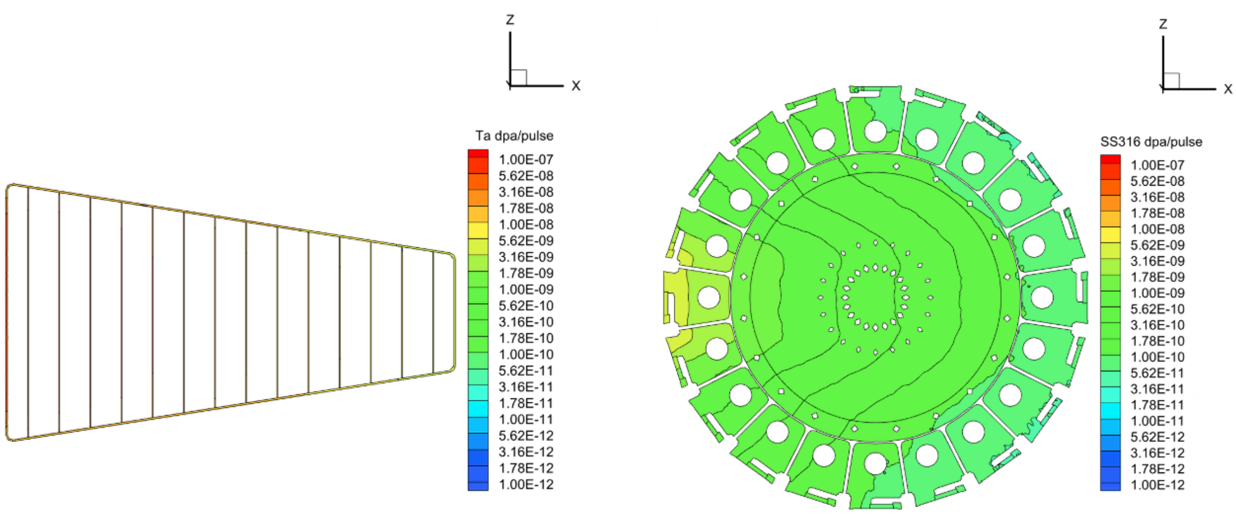

Figure 15. Horizontal cross section of the radiation damage per one pulse in tantalum in the front target segment (left) and stainless steel in all segments and shaft (right).

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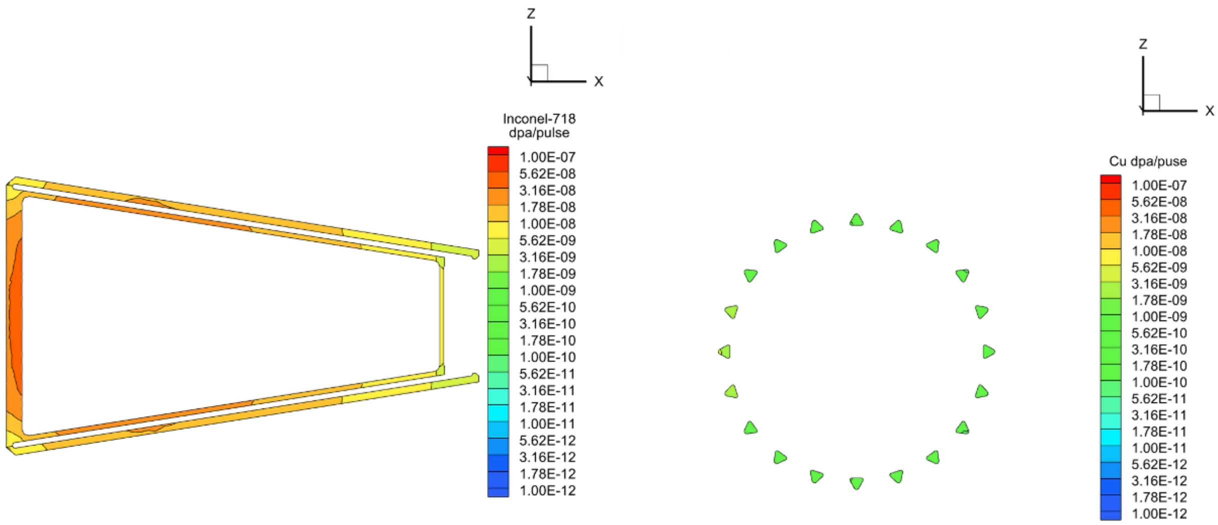

Figure 16. Horizontal cross section of the radiation damage per one pulse in Inconel-718 in the front target segment (left) and in copper chromium zirconium alloy in all segments (right).

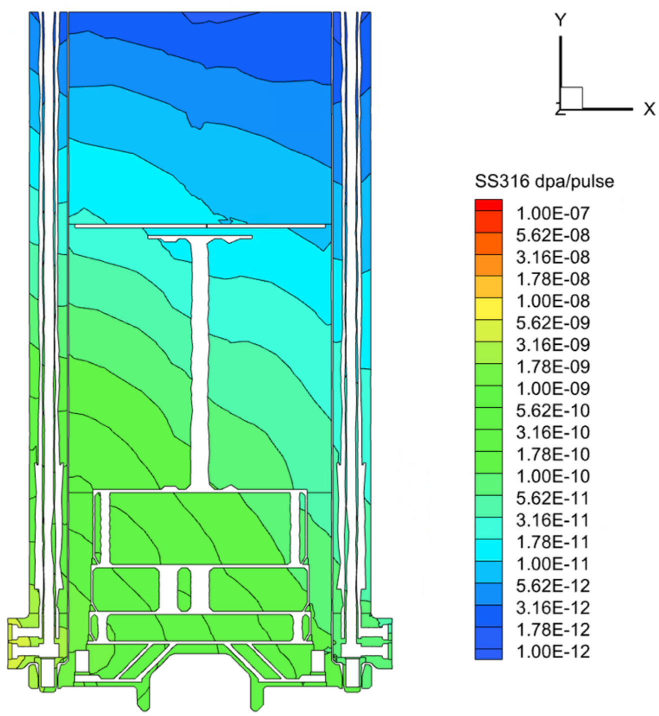

Figure 17. Elevation plot of the radiation damage per one pulse in steel portion of the target segment and in the lower portion of the shaft.

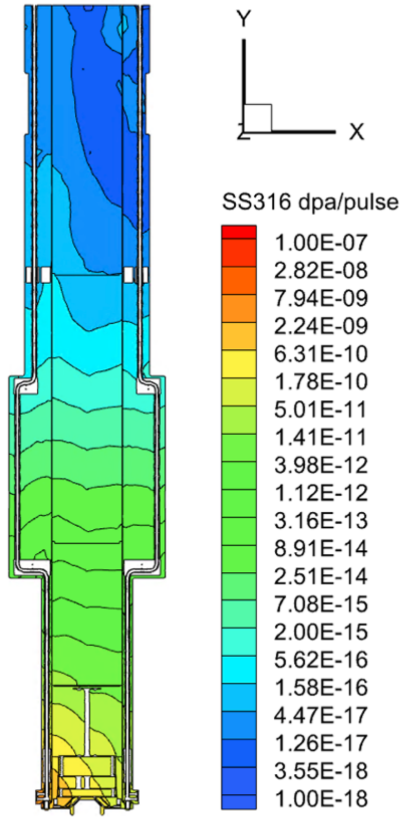

Figure 18. Elevation plot of the radiation damage per one pulse in the target shaft.

In a similar manner, dpa was integrated for the rotating target shaft. The maximum radiation damage in the shaft was determined as 0.12 dpa/year, or 1.2 dpa/10 years. With the 15 dpa lifetime limit for stainless steel 316, the lifetime of the shaft is then calculated as 125 years, well above the expected lifetime of the STS.

For the rotating target and shaft, the radiation damage was also calculated in the target staves (4.6-m long target segment components adjacent to the shaft, see Figure 1). During the target segment replacement process, the staves need to be cut at different elevations with a shear cutter, and the dpa levels were requested by the shear cutter manufacturers. Table 11 gives the radiation damage in the staves at several important elevations from the bottom of the shaft to the top.

Table 11. Elevation profile of the radiation damage per 10 years in the target staves.

Elevation	Radiation damage (dpa/10 years)
0 m (bottom of the shaft)	1.2
1 m	7e-3
1.3 m (below the donut)	1e-3
2.5 m (above the donut)	2e-6
3 m	2e-7
4.7 m (top of the shaft)	4e-9

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6. CONCLUSIONS

Energy deposition and radiation damage were calculated with MCNP6.2 using the unstructured mesh model of the final-design geometry of the STS target and target shaft.

Energy deposition in the target was calculated under four proton beam scenarios: nominal condition, maximally offset, overfocused, and diffused beam conditions. Energy deposition in the full length of the shaft up to the target drive room was calculated under nominal beam condition. Results were processed for individual target segments and materials and they were exported as .csv files for the subsequent structural stress and thermal engineering analyses.

Radiation damage was calculated in the target and full-length target shaft under nominal beam conditions. Results show that all the materials in the target satisfy Requirement 2301 – Segment dpa limit. Results also show that the lifetime of the shaft due to the radiation damage is longer than the expected lifetime of the STS facility.

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7. REFERENCES

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2. Attila4MC 10.3.0, "Release Notes, Silver Fir Software", www.silverfirsoftware.com, (2024).

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8. M-T. Kao, STS heating analysis, 2025.

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APPENDIX A. COMPUTER HARDWARE AND SOFTWARE

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APPENDIX A. COMPUTER HARDWARE AND SOFTWARE

These simulations were performed on either Saturn or Kryo, which are the Linux clusters owned and maintained by the STS Neutronics Groups. The MCNP module used for this analysis is

mcnp/mcnp6.2mod_20230411

In addition to that, Attila4MC, version 10.2, installed on ORNL PC117963 was used.

Tecplot was used to generate the figures.

APPENDIX B. LOCATION OF COMPUTATIONAL INPUT AND OUTPUT FILES

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APPENDIX B. LOCATION OF COMPUTATIONAL INPUT AND OUTPUT FILES

Geometry:

kryo.ornl.gov

/home/vlz/calculations/opt/target_study/s03020000-m8u-8800-a10000_asm-v167-analysis.stp

Results:

Listed below are locations of input (1st line) and output (2nd line) files for energy deposition and dpa calculations in the target and target shaft:

IN TARGET AND IN THE SHAFT UP TO THE ELEVEATION OF Y=80cm:

On Kryo in this directory:
/home/vlz/calculations/opt/target_study

ENERGY DEPOSITION:

Nominal beam:
joined_v147_2_inc.mcnp.i
joined_v147_2_inc.eeout

Overfocused beam:
joined_v147_2_57cm2.mcnp.i
joined_v147_2_57cm2.eeout

Defocused beam:
joined_v147_2_inc_95cm2.mcnp.i
joined_v147_2_inc_95cm2_out.eeout

Shifted beam:
joined_v147_2_offset.mcnp.i
joined_v147_2_offset.eeout

DPA :

Nominal beam:
joined_v147_2_inc_dpa.mcnp.i
joined_v147_2_inc_dpa.eeout

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IN THE SHAFT FOR THE ELEVEATION HIGHER THAN Y=80cm:

On Saturn in this directory:
/home/vlz/calculations/targetshaft/run1

ENERGY DEPOSITION:

Nominal beam:
v167_joined_all.mcnpum.i
v167_joined_all_out.eeout

On Kryo in this directory:
/home/vlz/calculations/targetshaft/run1

DPA :
Nominal beam:
v167_joined_all_dpa.mcnpum.i
v167_joined_all_dpa_out.eeout

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APPENDIX C. ADDITIONAL INFORMATION

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APPENDIX C. ADDITIONAL INFORMATION

Minimum requirements on the nominal and off-normal proton beam conditions used in this analysis are listed in Table 12.

Table 12. Nominal and off-normal proton beam conditions.

Case			Beam Loads					Body Loads			Water			State	Criteria
ID	Case	Power kW	Focus[a] 10^{11}	Profile Name	Offset v/h, mm	Pulses 10^8	Trips 10^5	Grav	Rot	Accel	Temp °C	Flow gpm	Press psi	State	Criteria
A	Nominal	700	6.24	$60cm^2$	0/0	1.35	1.25	Y	Y	N	32.2	7.5	36	WOL[b]	Req 1574[c]
B	Nominal-corner	700	6.24	$60cm^2$	8.5/12	1.35	1.25	Y	Y	N	32.2	7.5	36	WOL[b]	Req 1574[d]
C	Nominal-low flow	700	6.24	$60cm^2$	0/0	1.35	1.25	Y	Y	N	32.2	5.71	36	WOL[b]	Req 1574[d]
D	Overfocused	714	6.6	$57cm^2$	0/0	1.35	1.25	Y	Y	N	32.2	7.5	36	WOL[b]	Req 1574[c]
E	Diffuse	700	4.61	$94.5cm^2$	0/0	1.35	1.25	Y	Y	N	32.2	7.5	36	WOL[b]	Req 1574[d]

[a] $protons/mm^2/sec$
[b] Worst of Life material conditions (irradiated elastic modulus and thermal condictivity, but not strength)
[c] Fatigue methodology (weld reduction factors, etc.) determined in accordance with ASME ASME BPVC Sec. VIII.2, Part 5; allowable stresses are determined from best-in class irradiated material limits and not ASME fatigue curves.
[d] Fatigue lifetime criteria to be evaluated; minor deviations in life are acceptable for edge, corner, and worst case conditions

APPENDIX D. TECHNCIAL REVIEW DOCUMENTATION

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APPENDIX D. TECHNICAL REVIEW DOCUMENTATION

TECHNICAL REVIEW CHECKLIST

	Yes	No	N/A
Is the calculation well organized, legible, and complete?			
If excerpts from other sources are included in the calculation package, are the excerpts legible and properly referenced?			
Do the calculations cover the expressed purpose?			
Are all necessary elements included?			
Is the method used appropriate considering the purpose and type of analysis and the use and acceptability of the results (i.e. margin to limits)?			
Is the method in accordance with codes, standards, and regulatory requirements?			
Has the method been employed similarly elsewhere in industry?			
Are assumptions necessary to perform the analysis adequately described, justified, and reasonable?			
Are there any Unverified Assumptions (UVAs)?			
Were UVAs justified?			
Are the inputs sufficiently documented considering the purpose of the analysis?			
Is all the software used identified correctly (name, version, manual reference, OS, and compilers are documented)?			
Are the computer codes suitable for the present analysis?			
Does the model adequately represent the physical systems?			
Is the magnitude of the result reasonable?			
Are the directions of trends reasonable?			

Additional comments:

Technical Reviewer Date

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